Testing large mixing MSW solutions of the solar neutrino problem through Earth regeneration effects

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Large mixing MSW solutions to the solar neutrino problem appear to be currently favored by the data. We discuss the possibility of discriminating them by means of present and future experiments. In particular, we show that the study of energy and time dependence of the Earth regeneration effect can be useful in this respect.

1. Introduction

The available neutrino data from the Homestake [1], GALLEX-GNO [2], SAGE [3], Kamiokande [4] and Super-Kamiokande [5] experiments indicate a significant ν_e flux deficit with respect to the predictions of the Standard Solar Model (SSM) [6]. The ν oscillation mechanism represents a possible explanation of this deficit. In particular, recent analyses [7] show a preference of the data for the so-called MSW [8] (Mikheyev-Smirnov-Wolfenstein) solutions involving large mixing, usually indicated as "large mixing angle" (LMA) and "low δm^2" (LOW) solutions. We point out how present and future experiments can help to discriminate such two solutions through Earth regeneration effects.

2. Energy dependence of the Earth regeneration effect in SK and SNO

The slightly positive indication ($\simeq 1.3\sigma$) for an excess of nighttime to daytime events in Super-Kamiokande [5], if confirmed with higher statistical significance, would indicate the occurence of the Earth regeneration effect for ^8B neutrinos. Such indication, by itself, might not be sufficient to discriminate the LMA from the LOW solution, since a slight excess is predicted in both cases. On the other hand, the Earth regeneration effect depends strongly on the neutrino energy and, in principle, one could take advantage of this feature to discriminate the two solutions. In particular, starting from the simple observation that the Earth regeneration effect is stronger at low energy for the LOW solution, and at high energy for the LMA solution, we point out that it may be useful to study the night-day asymmetry in two separate energy ranges in both the Super-Kamiokande and the SNO experiments [7]. For definiteness, we consider the two following representative ranges for the total (measured) energy of recoiling electrons in SK and SNO,

$$\text{Low range (L)} = [5.0, 7.5]\,\text{MeV}\,, \tag{1}$$

$$\text{High range (H)} = [7.5, 20]\,\text{MeV}\,, \tag{2}$$

and calculate the night-day rate asymmetry in such ranges,

$$A_{H,L} = \left(\frac{N-D}{N+D}\right)_{H,L}\,. \tag{3}$$

Since one expects $A_H > A_L$ for the LMA solution and $A_H < A_L$ for the LOW solution, it is useful to introduce the difference

$$\Delta = A_H - A_L\,, \tag{4}$$

which should change sign when passing from the LMA region ($\Delta > 0$) to the LOW region ($\Delta < 0$).

Figures 1 and 2 show the result of our calculations of Δ (eccentricity effects removed) in SK and SNO, respectively, in the form of isolines at $\Delta \times 100 = \pm 0.5$, ± 1 and ± 2, superimposed to the current MSW solutions at 90%, 95% and 99% C.L., obtained using the latest experimental data. Such figures confirm that Δ sign effectively

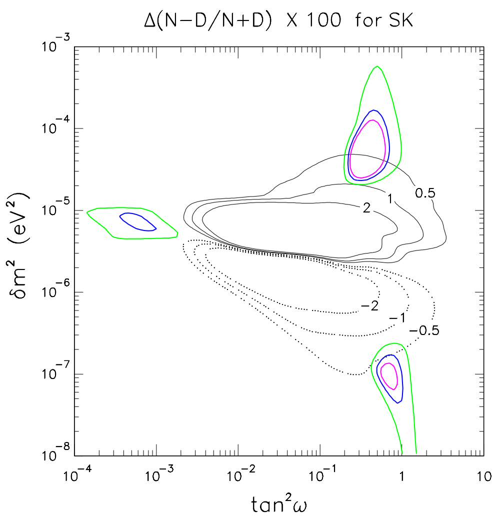

Figure 1. Curves of iso-$\Delta \times 100$ for Super-Kamiokande. The MSW solutions at 90%, 95%, 99% are also drawn.

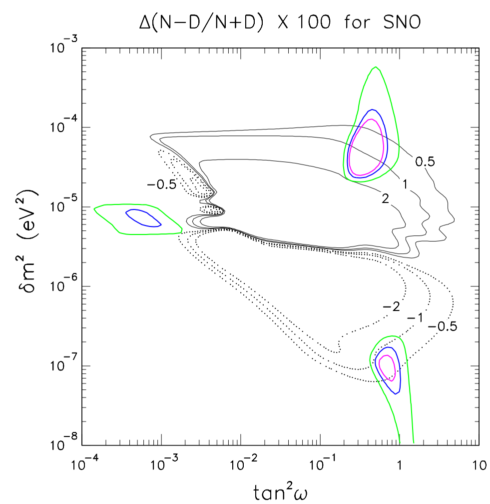

Figure 2. Curves of iso-$\Delta \times 100$ for SNO.

changes when passing from LMA to LOW solution, thus representing a useful test to discriminate the two large mixing angle solutions.

As one can notice in the figures 1 and 2, it turns out that, in the most favorable circumstances, the value of $\Delta \times 100$ can reach -0.5 (SK) and -1.0 (SNO) in the case of the LOW solution and 1.0 (SK) and 2.0 (SNO) for the LMA. This small effect could be observable in the two experiments, provided that they can reach a sensitivity to Δ at a (sub)percent level. However, the simple preference of the SK and SNO experiments for a definite Δ sign would already constitute a useful information, corroborating other tests envisaged to solve the LOW-LMA ambiguity [9–11].

Our choice of the low and high energy ranges in Eqs. (1, 2) is only representative, and it should be tuned to reach the best compromise between sensitivity to the energy dependence of Earth regeneration effect and statistical significance. For instance, one could also enhance the sensitivity to the energy dependence by calculating the day-night asymmetry in a larger number of bins (D-N asymmetry spectrum); however, the statistical significance would decrease in each bin. The optimal compromise requires dedicated experimental studies.

3. Testing LOW solution through time variations in BOREXINO and GNO

The Earth regeneration effect occurs at relatively low values of δm^2 for low energy (^{7}Be and pp) neutrinos, that can be detected by the two experiments BOREXINO (based on ν_e scattering) and GNO (based on ν_e-Ga absorption). The first is a real-time experiment, able to detect a possible regeneration phenomenon as a day-night asymmetry of the event rate. The second is a radiochemical experiment with a signal extraction timescale of ~ 1 month. It can, however, detect Earth effect in the form of a seasonal modulation of the signal [12]. Indeed, during winter, the nighttime is longer compared to summer and, furthermore, the trajectory of neutrinos probes inner layers of the Earth (in particular, the Earth core is crossed only during winter [12]).

In Fig. 3 we show the results of our calculation of the day-night asymmetry ($A_{DN} \times 100$) of the event rate for BOREXINO. In the same plot we show the current solutions of the solar neutrino problem at 90%, 95% and 99% C.L. (for 2 d.o.f.) respectively. This figure shows that the day-night asymmetry expected in BOREXINO in the region of the LOW solution is expected to be in the range $1\% - 20\%$.

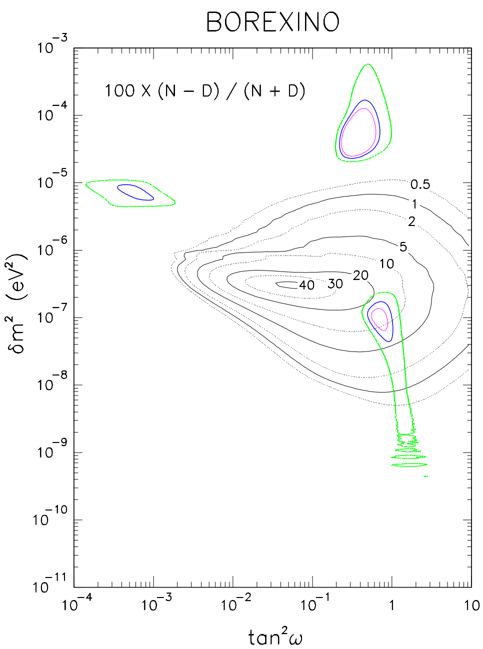

Figure 3. Curves of iso-$A_{DN} \times 100$ for BOREXINO. The current MSW+quasivacuum solutions at 90%, 95%, 99% are also drawn.

Figure 4 shows the iso-lines of Winter-Summer rate difference R_{WS} (in SNU) expected in GNO due to the Earth regeneration effect (eccentricity effect removed). Winter and Summer periods are defined as

$$\text{Winter} \;\simeq [23\text{ september}, 21\text{ march}]\,, \tag{5}$$

$$\text{Summer} \simeq [22\text{ march}, 22\text{ september}]\,. \tag{6}$$

Notice that the sensitivity in the LOW region is almost maximal since GNO is predominantly sensitive to low-energy pp ν's, as compared with BOREXINO, which is more sensitive to the ^{7}Be line ν's. This circumstance makes these two experiments intrinsically different in testing the LOW solution. The two tests are also complementary in tracking the origin of the time variations: a possible seasonal signal in GNO, if originated by vacuum (instead of MSW) oscillations, should not produce a N-D asymmetry in BOREXINO.

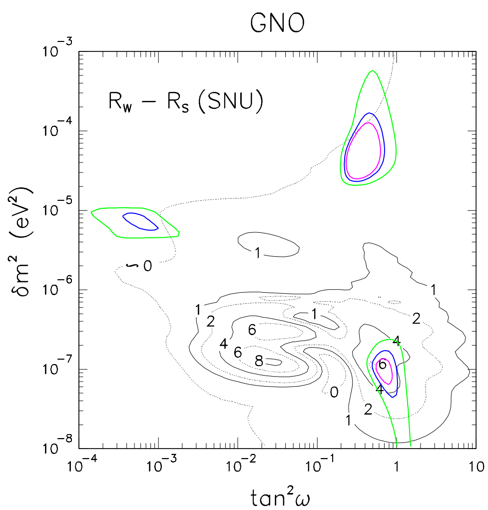

Figure 4. Curves of iso-R_{WS} (in SNU) for GNO.

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